Charmed Mesons in Deep Inelastic Scattering at HERA

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on behalf of the
H1 and ZEUS collaborations

Outline:

• HERA & kinematics at HERA
• Theory of open charm production in ep-scattering
• Inclusive cross sections of D meson production
• Charm contribution $F_2^c$ to the proton structure function
• Conclusions
The HERA accelerator

\[ s = 318 \text{ GeV} \]

This talk: Results from HERA-II running only
Open Charm Production in DIS

Predominantly: Boson-Gluon-Fusion (BGF)

Ep-Kinematics:
\[ \sqrt{s} = 318 \text{ GeV (energy c.m.)} \]
\[ Q^2 = -q^2 \text{ (photon virtuality)} \]
\[ x = x_{\text{BJ}} \text{ (fraction of proton momentum carried by the struck quark)} \]

2 kinematic regimes:
\[ Q^2 \approx 0 \text{ GeV}^2 : \text{Photoproduction (}\gamma p\text{)} \]
\[ Q^2 > 1 \text{ GeV}^2 : \text{Electroproduction (DIS)} \]

Factorisation:
\[ \sigma^h = \text{PDF} \otimes \text{M.E.} \otimes \text{FF} \]
Theory approaches for charm production

Massive fixed order QCD calculation, FFNS
- heavy flavours generated dynamically via BGF
- correct threshold treatment
- valid for $\mu^2 \approx O(m_c^2)$
- expected to fail at some scale $\mu^2 \gg m_c^2$

Model for charm production in DIS and inclusive charm meson production available: HVQDIS

Massless calculation (ZM-VFNS)
- massless charm as part of the proton
- not valid at threshold
- expected to work at HERA at large $p_t$

Generalized mass calculation (GM-VFNS)
- massive at $\mu^2 \approx m_c^2$ and massless at $\mu^2 \gg m_c^2$
  - no predictions for the final state in DIS ($F_2^{cc}$ only)

will be compared to data
Monte Carlo event generators

**RAPGAP**
- collinear partons in the proton
- massive matrix element calculated in LO QCD
- higher order contributions via parton showers
- parton evolution based on DGLAP equations

**CASCADE**
- only gluons in the proton
- un-integrated gluon density \((k_T)\)
- massive off-shell matrix element
- initial state parton showers to all orders
  based on CCFM equations \((P_{gg}\text{ only})\)
- final state parton showers à la Jetset

Hadronization via Lund String model (Jetset)
Reconstruction of $D^{*-}$ mesons

- **Golden decay mode:**
  $$D^{*-} \rightarrow D^0 \pi^+ \pi^- (+c.c.) \rightarrow K^- \pi^+$$

- **Kinematic range:**
  $5 < Q^2 < 100 \text{ GeV}^2$ and $100 < Q^2 < 1000 \text{ GeV}^2$
  $0.02 < y < 0.7$
  $p_T(D^*) > 1.5 \text{ GeV}$
  $|\eta(D^*)| < 1.5$

- **Data Sample**
  350 pb$^{-1}$
  (2004–2007)
Inclusive D*⁺ cross sections - pₜ, η

Reasonably well described by NLO QCD
different shapes in pₜ and η for Q² < 100 GeV² for both PDF’s

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Inclusive $D^{*+}$ cross sections - $Q^2$

- Reasonably well described by NLO QCD – albeit different shape
- RAPGAP fails to describe the data in full $Q^2$ range
- CASCADE yields a better description

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Reconstruction of $D^+$ and $D^0$ mesons

- Reconstructed decay modes:
  
  - $D^+ \rightarrow K^- \pi^+ \pi^+ \,(+\,c.c.)$
  - $D^0 \rightarrow K^- \pi^+ \,(+\,c.c.)$

  ($D^0$ not from $D^{*+}\rightarrow D^0\pi^+$)

- Decay products originate from reconstructed secondary vertex with significance
  
  $$S_{XY} = \frac{L_{XY}}{\sigma(L_{XY})} > 3 \,(D^+)$$
  $$> 1 \,(D^0)$$

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**D\(^+\) and D\(^0\) mesons and selection**

- **Kinematic range:**
  - \(5 < Q^2 < 1000 \text{ GeV}^2\)
  - \(0.02 < y < 0.7\)
  - \(1.5 < p_T(D) < 15 \text{ GeV}\)
  - \(|\eta(D)| < 1.6\)

- **Data Sample:**
  - 133.6 \(\text{ pb}^{-1}\)
  - (2004/05) \(e^-p\)

**Diagram:**

- 
  - Graph showing distribution of combinations.
  - Data points for \(e^-D^0\) and \(e^-D^+\) channels.
  - ZEUS (133.6 \(\text{ pb}^{-1}\))
  - Gaussian fit + Background

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Inclusive D cross sections – p_T and \eta

Good description of data by massive NLO QDC calculations HVQDIS
Inclusive D cross sections - $Q^2$ and $x$

Good description of data by massive NLO QCD calculations HVQDIS

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Charm contribution to the proton structure function

Charm structure function:

\[
\frac{d^2 \sigma}{dx dQ^2} = \frac{2\pi \alpha_{em}}{Q^4 x} \left( Y_+ F_2^{cc} - \frac{y^2}{Y_+} F_L^{cc} \right) \quad \text{with} \quad Y_+ = 1 + (1 - y^2)
\]

visible inclusive D cross sections are converted to \( F_2^{cc} \) via

\[
F_2^{cc} (\exp) = \frac{\sigma_{vis}(\exp)}{\sigma_{vis}(\text{theory})} F_2^{cc} (\text{theory})
\]

complication: visible range of detected D mesons covers only \( \approx 30\% \) of the phase space

⇒ introduces model dependent extrapolation uncertainties (more details see next talk by K. Lipka)
Massive NLO predictions with PDF's from global analyses or inclusive $F_2$ agree well with data

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\(F_2^{cc}\) from HERA

- Large scaling violations in \(F_2^{cc}\)
- Data sensitive to the gluon density in the proton

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Here $F_{2}^{cc}$ is measured.
Conclusions

• New results on D meson production in DIS at HERA have been presented

• Inclusive visible cross sections are reasonably well described by
  • LO+PS Monte Carlo RAPGAP and CASCADE
  • massive NLO calculation HVQDIS

• Charm contribution $F_{2}^{cc}$ to the proton structure function has been extracted
  • $F_{2}^{cc}$ data cover a large part of the $(x,Q^2)$ plane accessible by inclusive $F_2$ measurements
  • $F_{2}^{cc}$ data will crosscheck the gluon density
  • Scaling violations in $F_{2}^{cc}$ significantly larger than in $F_2$
Backup